

COMPUTATIONAL URBANISM - A PARAMETRIC RELATIONAL URBAN MODEL FOR URBAN PLOT RATIO ALLOCATION

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ABSTRACT: Urbanism operates with massive dynamic urban data. For that, various urban code systems have been implemented for data registration. However our capacity of processing and cross breeding these data is rather limited. This paper stresses the concept of similarity matrix as the unifying factor to construct a parametric relational urban model that can meaningfully cross breeding different kinds of urban data and synchronize other urban analysis tools, such as space-syntax. This parametric relational urban model can dynamically adapt to the development of its physical counterpart in selected aspects. The internal similarity pattern of the existing urban fabric exposed by this urban model, can provide rational suggestions to ensure harmonious urban development strategies that preserve the typological urban form for particular city at study. Besides, it is also possible to incorporate top-down intervention input, by which radical planning intentions can be tested and compared with real-time feedback of their impacts on the entire urban fabric.

KEYWORDS: planning culture, bottom up system, similarity, dynamic equilibrium

1 INTRODUCTION

Urbanism, by nature, operates with massive dynamic urban data. For that, various urban code systems have been implemented for data registration. However, compared with the huge amount of data accumulated, our capacity of processing and cross breeding these data is rather limited. This problem starts to become more crucial with the switch of urban planning culture from top-down towards bottom-up approach, which regards the urban fabric as a self-organizing complex system that exhibits great complexity and huge amount of internal interactions. Under this light, new urban question is legitimated: if it is possible to construct a common platform to process and cross breeding different kinds of urban data so as to improve our understanding/influence on the complex urban fabric from a bottom-up point of view?

This paper proposes the concept of similarity matrix as one possible solution to the question above. Similarity matrix refers to the matrix of mutual similarity coefficients for all actors within the same bottom-up urban fabric. The definition of actor in this context can be rather flexible. It can be set as building, street or urban plot, as long as there are sufficient urban data to support such subdivision method. By cross-breeding different kinds of urban data that are associated with such subdivision method, the parametric relational urban model can be constructed to reflect the internal similarity pattern of the physical urban fabric. This parametric urban model can provide rational suggestions to ensure harmonious urban development/renewal strategies that preserve the typological urban form for particular city at study. Besides, it also allows top-down intervention inputs, by which radical planning intentions can be tested and compared with real-time feedback of their impacts on the entire urban fabric. Moreover, this parametric relational urban model can evolve together with physical city, each new relevant update of the physical city, once registered into the urban model, will trigger a reconstruction of the internal similarity matrix of the urban model which ensures the urban model to be constantly up to date to reflect the new urban condition and make planning suggestion accordingly.

This resultant self-regulatory urban model with flexible intervention inputs, is not only a credible tool for understanding the hidden similarity pattern of urban fabric, but also an effective platform to activate and compare different urban design proposals. Following the basic principle of the parametric relational urban

model, different applications can be envisioned that reveals the great potential of enriching urban governance and planning with computational technology from a bottom-up point of view. This paper will elaborate on the first application of the parametric relational urban model, the Urban Plot Ratio Allocation software, to introduce its computation principle and application value in the urban design scenario.

2 ABSTRACT PRINCIPLES FOR THE DECISION OF PLOT RATIO

The Plot Ratio or Floor Area Ratio (FAR), which is used in zoning to limit the amount of construction in many countries, is the ratio of the total floor area of buildings on a certain plot to the size of the land of that plot. The decision of the plot ratio is usually based on the experience of planners and the negotiation between the related groups, which refers to not only the top-down intentions of the planner or mayor, but also mutual references of many other similar plots in the city from a holistic point of view. Thus, the decision of a block's plot ratio in the planning process can be concluded with the following two aspects:

(1) Evaluating the block's potential for development, for example the condition of the site, transportation, function, environment, etc., at the same time satisfying the control requirement of the urban codes on the block. More potential lead to larger plot ratio and tighter control means less development. So the comparison between the blocks is much more meaningful, which fetches out the more important second aspect.

(2) Referring to the plot ratio of the blocks with similar land conditions and urban codes. To be fair, all the similar blocks should be considered no matter its plot ratio is high or low. And the higher the level of similarity between two blocks goes, the higher the mutual reference value between them goes. Actually this is the main principle followed in the decision process.

In general, the decision of plot ratio is a consensus process based on the reference to the value of the similar blocks with relatively rational plot ratio, which usually adulterates subjective and unfair factors because many different people and groups are involved in the process. Moreover, except for referring to the similar existing blocks, the decision of a block has to consider the influence to other blocks to be developed whose influence to their similar blocks should also be investigated... as for the complexity of all the interconnections between plots and the huge amount of information that need to be processed, a precise understanding of this process is far beyond direct human comprehension. What is presented in this paper is the software to simulate the interaction between blocks with the above mentioned principles: Firstly the evaluation of each block is quantified, based on which the similarity matrix for all the blocks can be created. When the plot ratio of the existing blocks input the system, the software will calculate the value of the pendent blocks gradually with a large number of interactions between all the blocks and the system tends to the equilibrium.

The algorithm, operation and application of the software will be clarified in the following sections with the case of Changzhou, a Chinese city.

3 TECHNICAL PROCESS AND ALGORITHM

The workflow of the urban plot ratio allocation software may be interpreted as the following four steps (Figure 1).

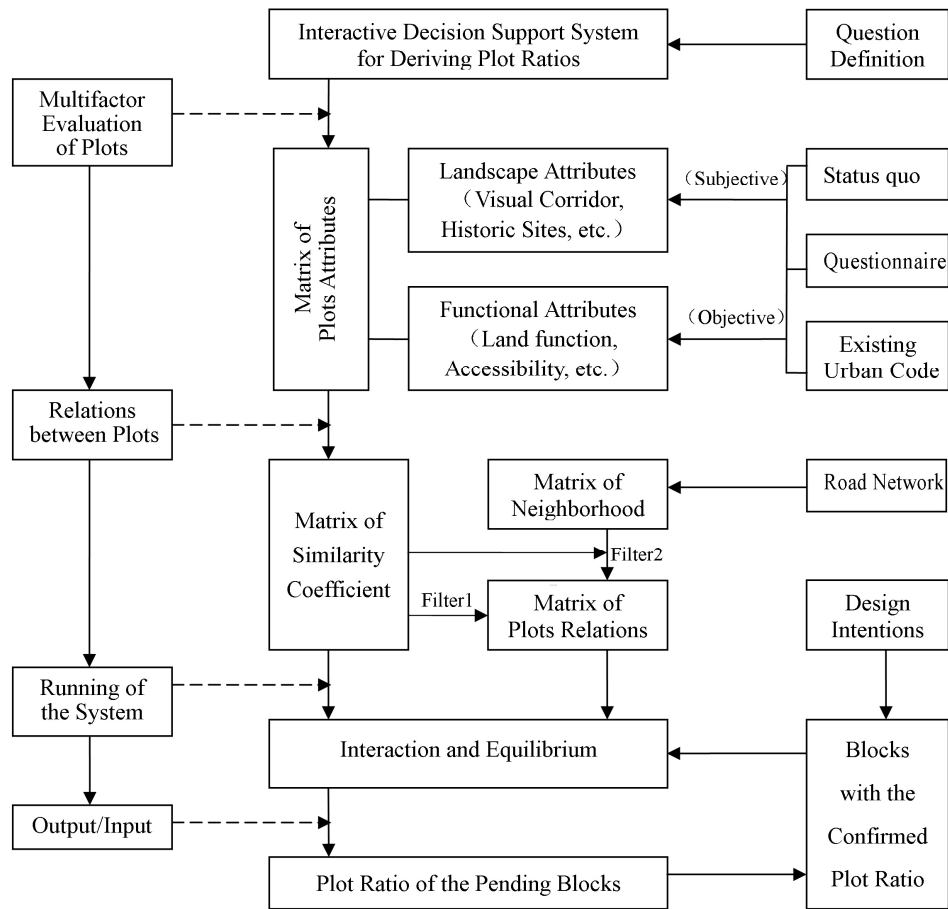


Figure 1 Plot Ratio Allocation algorithm workflow

3.1 Multifactor evaluation of plots

Firstly, the urban land is divided into plots which are numbered one by one according to the planning road network. Then, a list of universal plot attributes will be introduced, such as land function, accessibility, etc. As for different kind of plot attribute, different evaluation method can be applied, such as comparing available urban data, adopting urban analysis software and analyzing questionnaire. All of the plots will be evaluated separately for each kind of universal attributes. The result of this evaluation is a matrix of plot attribute factors set between 0.5 and 1.5, which reveals the potential for each plot to be developed. Higher value here means more potential for development, and vice versa. These evaluated block attribute factors may be grouped into the following two types:

(1) Function factors. These are the objective effect of the existing urban codes and master plan, which may include land function, accessibility, etc. In the case of Changzhou, the factor value of land function gets lower and lower from commercial, office, residential land to industrial and warehouse land determined by the master plan. And the accessibility of a plot is defined as the average of the two largest integration value among the axes surrounding it based on the space syntax analysis of the road network (Hillier 1996). The conversion of the value to the range of 0.5 and 1.5 is expressed with Eq. (1)

$$A_x = \frac{I_x - I_{min}}{I_{max} - I_{min}} + 0.5 \quad (1)$$

Where A_x is the accessibility value of a plot, I_x is the average of the two largest integration value among the axes surrounding the plot, I_{min} and I_{max} are the minimum and maximum value among all the I_x .

(2) Landscape factors. These are the subjective factors based on the holistic conceiving of the urban form and landscape, which may include the control of visual corridors, historic sites, key areas to natural open space, etc. In the case of Changzhou, values of the plots under the visual corridors are set as 0.5; values of the plots beside the estuaries, rivers and public green space are set between 0.7 and 1.5 according to its

sensitivity to the landscape; values of the plots with the national, provincial or municipal monument are set as 0.5, 0.8 and 1.1, the historic sites are set as 0.9. Values of other plots without control requirement are set as 1.5.

According to the above mentioned evaluation standard (Figure 2), the matrix of the plots attribute factors is created which is the basis of the similarity matrix of all plots. It should be pointed out that different cities may choose different attributes according to their characters and the comparative relation is much more meaningful than the absolute value of each attribute factor.

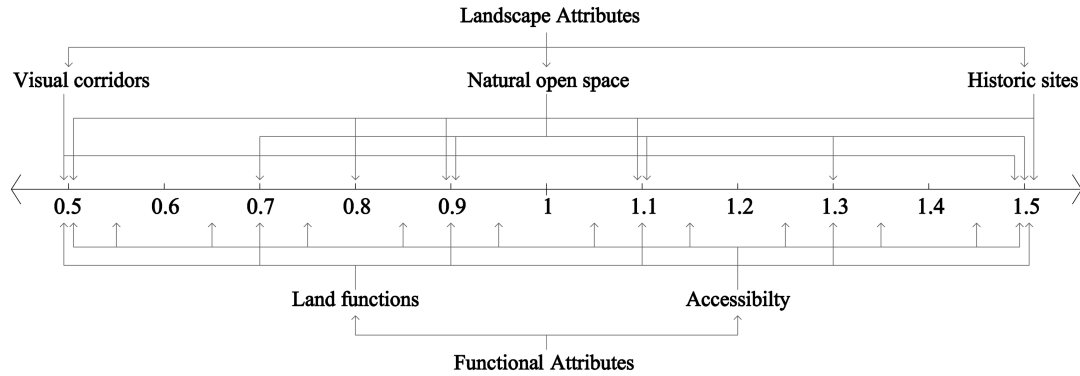


Figure 2 Multifactor evaluation standard of land attributes in Changzhou case

3.2 Relations between blocks based on their similarity

The similarity coefficients between all the blocks may be calculated based on the multifactor evaluation of plots by the following formula, Eq. (2), adapted from the algorithm of standard deviation:

$$S_{ij} = 1 - \left\{ \frac{[F_{1(i)} - F_{1(j)}]^2 + [F_{2(i)} - F_{2(j)}]^2 + \dots + [F_{n(i)} - F_{n(j)}]^2}{n} \right\}^{1/2} \quad (2)$$

$i = 1, 2, \dots, m; j = 1, 2, \dots, m$

Where S_{ij} is the similarity coefficient between plot i and plot j , $F_1, F_2, \dots, F_n$ are the various attribute factors of the plots, n is the number of attribute factors, m is the number of plots. As the values of all the attribute factors are set between 0.5 and 1.5, the similarity coefficient calculated with this formula will fall in the range of 0-1. The two blocks will share higher level of mutual referential relation if their similarity coefficient tends to 1.

Then a threshold for the general similarity coefficient is set to control the overall level of connectivity within the entire system, i.e. if the similarity coefficient of two blocks is more than this threshold, the two blocks will be regarded as interconnected and the plot ratios of them will refer to each other. The threshold is set as a variable in the software and the default value is 0.8.

The neighboring condition may be considered as a special kind of similarity, which is the reason why the neighboring blocks usually have the priority to refer to each other for the decision of plot ratio allocation. To simulate that, the threshold for the similarity coefficient of the neighboring blocks is set lower than the general similarity coefficient threshold. The default value is 0.75 in the software.

Therefore the similarity matrix is created which is the ground for the interaction and mutual reference between blocks. It should be pointed out that the degree of the interconnection is also depended on their similarity coefficient, which will be clarified in the next section.

3.3 Interaction and equilibrium

In total, there are only three types of plots defined, existing blocks, pendent blocks and exclusive blocks. The existing blocks refer to the blocks whose plot ratios are regarded as rational and will be kept constant throughout the computation process. The pendent blocks refer to the blocks whose plot ratios are subject to change during the computation process. The exclusive blocks refer to a collection of special blocks that exhibits irrational plot ratio due to particular reasons, and they are naturally excluded from system interaction.

All existing and pendent blocks will iterate through all their connected blocks for their plot ratios and the shared similarity coefficients as the basic parameters to realize the internal system interaction. If we consider the system to have only two active blocks as A and B, who share the same similarity coefficient of S-ab, then the new plot ratio of A for next iteration will be the sum of current plot ratio of A and the amendment factor it receives from B, which can be calculated by multiplying S-ab with the difference of plot ratio between B and A. For the computation system operating with multiple active blocks, the process can be expressed with Eq. (3).

$$P_{x+1} = P_x + \sum_{i=1}^n \frac{(P_i - P_x) S_i}{n} \quad (3)$$

Where P_x is the plot ratio of a block after x round calculation, P_{x+1} is that after $x+1$ round calculation, P_i is the plot ratio of every connected blocks, S_i is the similar coefficient to every connected blocks, n is the number of the connected blocks. When the system tends to equilibrium P_{x+1} will be almost equal to P_x .

It is necessary to include the existing blocks within the interactive system, as they may serve as bridges to facilitate interactions between pendent blocks that are not directly connected. Thus, to preserve their confirmed plot ratio to be constant while realizing their conductive function, a mirror value is introduced, that can be used to transmit the internal force received by an existing block back to its connected blocks. The relation between mirror value and calculated value for existing blocks is written as Eq. (4).

$$P_{x+1}' = 2P_0 - P_{x+1} \quad (4)$$

Where P_0 is the confirmed plot ratio of an existing block, P_{x+1} is the plot ratio calculated by Eq. (3), P_{x+1}' is the mirror value of P_{x+1} to P_0 and will be used in Eq. (3) for the next round calculation. Thus all the interactions in the system are expressed. When the system tends to equilibrium P_{x+1}' will also be almost equal to P_x .

Figure 3 shows the plot ratio self-organizing process in the case of Changzhou, where the existing blocks are displayed in sandy beige and the pendent blocks are in puce which were flat at first and then grew up and down before equilibrium at last. The fluctuant process of the pendent blocks are demonstrated in Figure 4, where the plot ratios of all pendent blocks were set to 0 at first and then undertook their individual fluctuation curve until they tended to stabilization at the fourteenth round of calculation. Different initial plot ratio settings for pendent blocks will not make any difference to their end result at equilibrium. As given enough iterations, the stabilized plot ratios for the pendent blocks will only be determined by the combination of the confirmed plot ratios from their connected existing blocks and the predefined system similarity matrix. Thus, when the system reaches equilibrium, the plot ratios combination of pendent blocks will be the unique rational outcome derived from the self-organizing process.

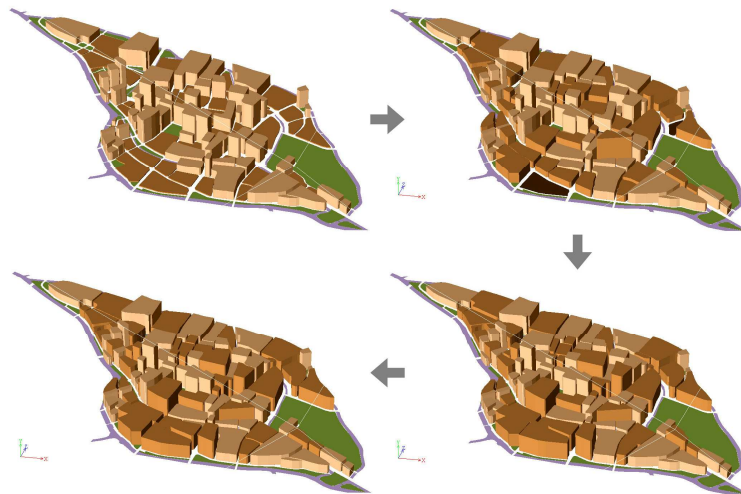


Figure 3 Interaction process of the blocks (Changzhou)

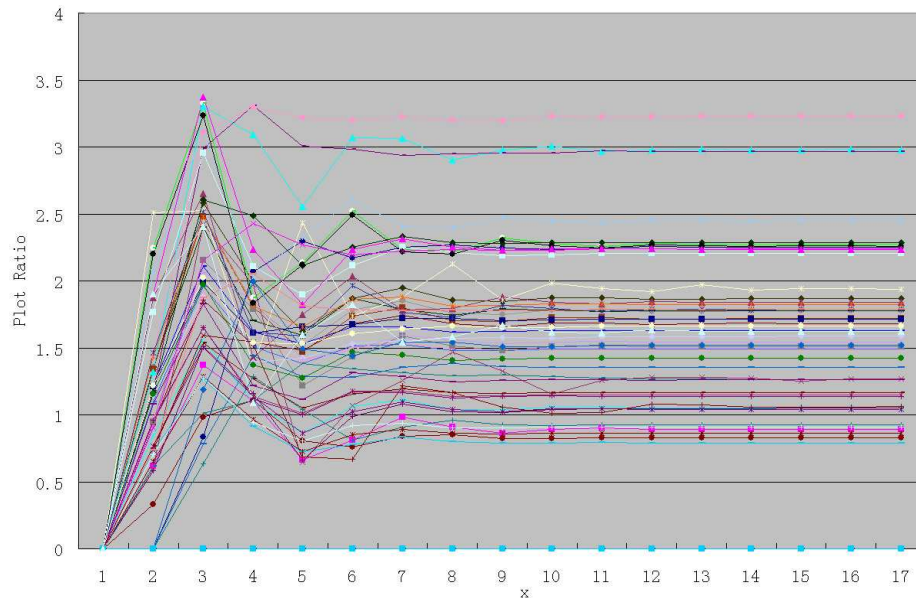


Figure 4 Fluctuant Process of the Pendent blocks (Changzhou)

Figure 5 records vibrations of calculated value (P_{x+1}) and mirror value (P_{x+1}') of the existing blocks, Eq. (4). The definition of system equilibrium for this software comes from the fact that the difference between subsequent calculated value and mirror value from all existing blocks infinitely tends to 0. Thus, instead of a static equilibrium, this software operates with a dynamic one that literally represents the ever lasting internal tension of the physical urban fabric.

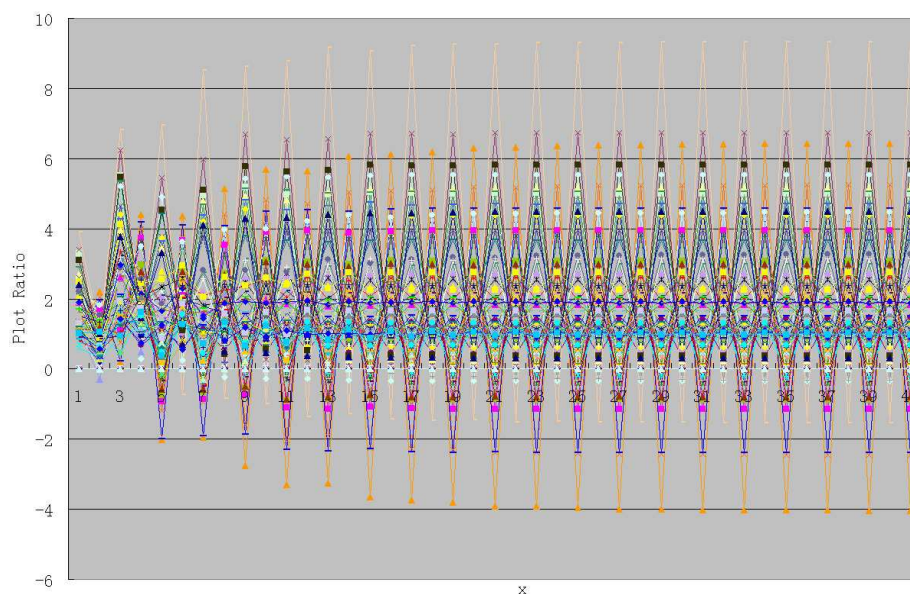


Figure 5 Calculated and mirror value of the existing blocks (Changzhou)

3.4 Input/Output and circular running

The inputs to this software include a vector based 3d urban model and spread sheet data of plot evaluation factors. The outputs will be a transformed 3d urban model and spread sheet data of suggested plot

ratios for all pendent blocks. Designed as an open system on circular running, this software can seamlessly incorporate real-time external top-down design intensions into the running system. Designer can assign arbitrary plot ratio to any pendent block then convert that block into an existing block so as to observe the impact of such planning intension. Or the designer can free any existing block as pendent block, so as to let the system calculate the optimized plot ratios for this particular block. Besides, multi layered information will also be displayed to facilitate the design decision making process.

4 PARAMETERS AND THEIR MEANINGS IN URBAN DESIGN

All the parameters to be displayed and controlled are presented in the right hand window of the software. (Figure 6) In general, these parameters can be concluded with four modules:

(1) Information display which shows the basic information about the current selected block including its number, plot ratio, factor scores, connected and neighboring blocks. The current selected block will be blinking and its connected blocks will be presented in red color in the view window (Figure 6).

(2) Statistical analysis which shows the plot ratio's changing process of the current selected block and the sum of all the blocks.

(3) Import and export which is used to update the input urban data and output the outcomes.

(4) Design parameters which are the most important module to carry out the design intervention directly. The design parameters will be interpreted in following two types:

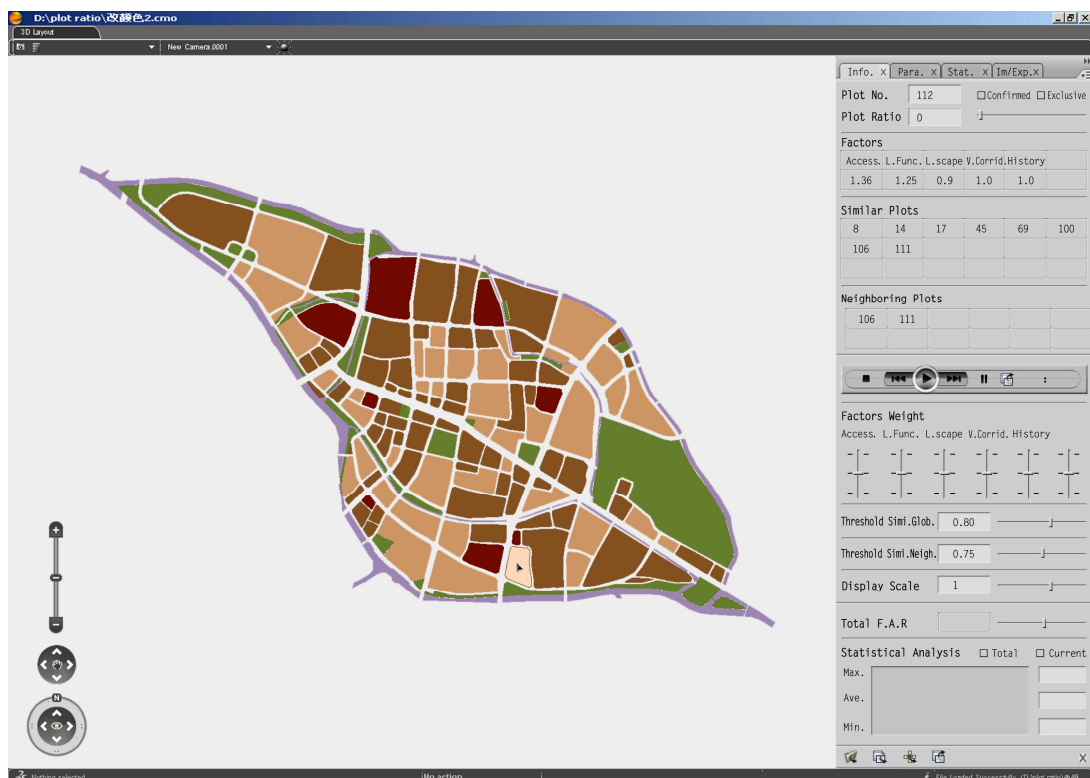


Figure 6 Interface of the software with the panel on the right

4.1 Parameters on plot

The plot ratio of each plot may be modified on fly. As for the existing blocks, such modification will be directly reflected in the next iteration of computation. As for the pendent blocks, designer will need to further declare the target block as an existing block by choosing the option of 'Confirm' in the panel (Figure 6). Figure 7 shows the general disturbance process after one pendent block was manually assigned with a bigger plot ratio and confirmed as an existing block. The obvious plot ratio disturbance at the 15th iteration faded away for most of the pendent blocks, however there are a few plot ratios heavily affected by this modification. The reading of figure 7 fits well very with the system assumption, which indicates certain plot

ratio fluctuation will heavily affect the directly associated pendent blocks, while have less impact on the iteratively associated ones. Therefore, by observing the general impact of certain top-down design intension, this software can be applied as an effective tool to verify the planner's intention and activate their creation.

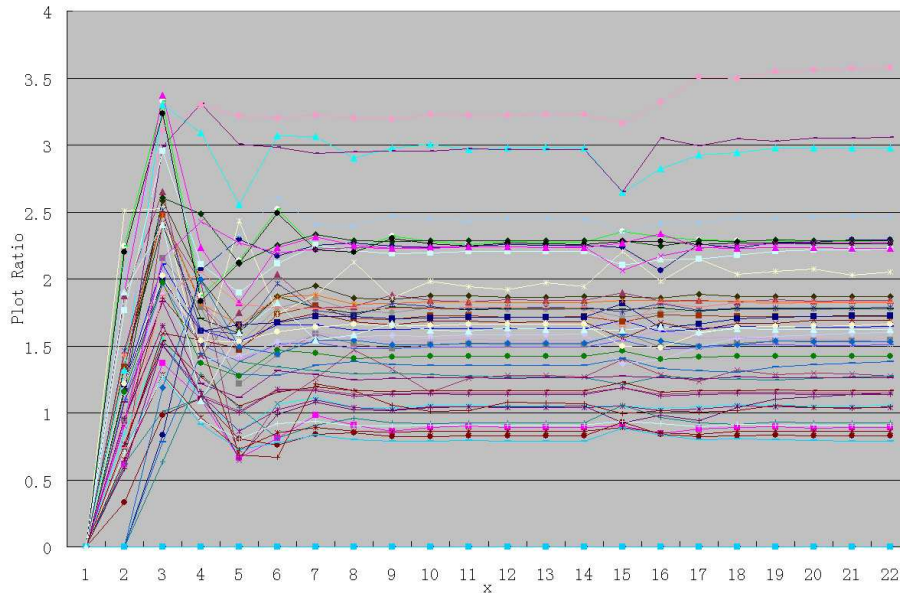


Figure 7 Disturbance process by changing a blocks plot ratio

Some special blocks, for example those with special functions or with unusual development may be regarded as the enclaves by choosing the option of “Exclusive” in the panel (Figure 6). Then they will not be involved in the interaction process. All these parameters together ensure a flexible and effective control of the software to cope with the complex urban design and planning situation.

4.2 Parameters on relations between plots

The general relations between blocks can be controlled with two methods. The first one defines the global similarity threshold to manage the overall level of connectivity. The second one changes the combination of factor weight to modify the initial similarity matrix. These two methods will be specified as following:

(1) The overall level of connectivity between blocks can be adjusted by changing the value of “Threshold Simi.Glob.” in the panel (Figure 6). This parameter defines the similarity threshold for any two blocks to be regarded as connected, i.e. the smaller value of the threshold means each block may be connected to more blocks and the consequence will be that all the pendent blocks tend to have equal plot ratio with each other. This parameter can be changed on fly, as shown in Figure 8, when the threshold was changed from 0.80 to 0.70 at the 14th iteration, the plot ratios range of all pendent blocks get smaller.

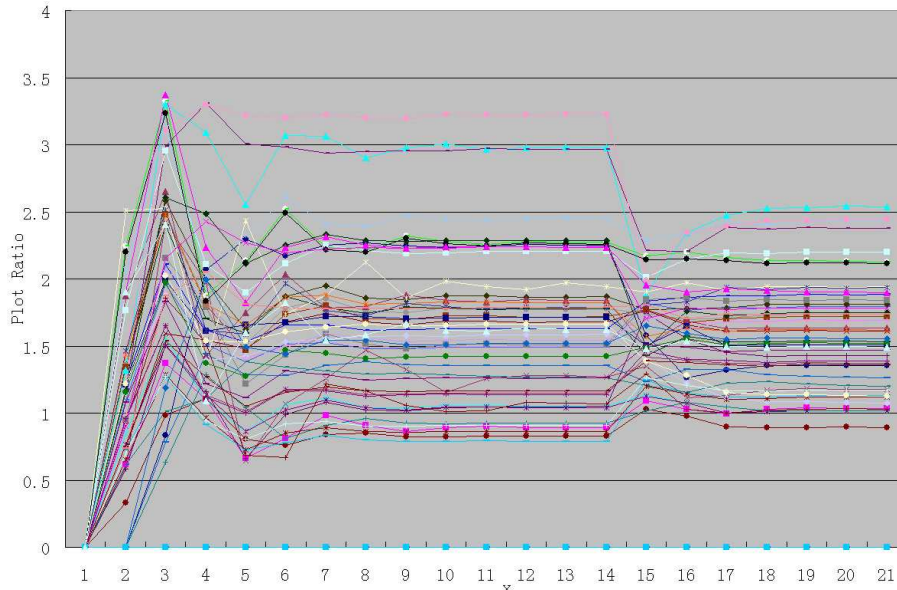


Figure 8 Disturbance process by changing the threshold of similarity

There is also a separate similarity threshold set for controlling neighboring connectivity. This threshold can be controlled by adjusting the value of “Threshold Simi.Neigh.” in the panel (Figure 6) to bring more flexibility to the designers.

(2) The factor weight for all plot attributes are set as 1 by default. This means all kinds of plot attributes will be treated equally while constructing the similarity matrix. However, it is also possible at the initial stage to setup different factor weight combination to meet special design preferences that intentionally emphasize or deemphasize certain plot attribute. This can be realized by alter the factor weight setting in the panel (Figure 6). Eq. (5) illustrates the relation between factor weight parameter and similarity coefficient.

$$S_{ij}' = 1 - \left\{ \frac{[F_{1(i)}^{x_1} - F_{1(j)}^{x_1}]^2 + [F_{2(i)}^{x_2} - F_{2(j)}^{x_2}]^2 + \dots + [F_{n(i)}^{x_n} - F_{n(j)}^{x_n}]^2}{n} \right\}^{1/2} \quad (5)$$

$i = 1, 2, \dots, m; \quad j = 1, 2, \dots, m$

Where S_{ij} is the similarity coefficient between plot i and plot j , $F_1, F_2, \dots, F_n$ are the various factors of the plots, n is the number of factors, m is the number of plots, $x_1, x_2, \dots, x_n$ is the factor weight of different plot attribute.

5 CONCLUSIONS AND FUTURE WORK

The Urban Plot Ratio Allocation software introduced in this paper is a flexible and credible tool for the decision making of plot ratio allocation, based on the understanding of urban form as a self-organizing complex system regulated by its internal similarity matrix. By incorporating several methods for top-down intervention, different development intentions can be verified and compared with real-time feed back that provides an effective and transparent channel for the communication of different urban development/renewal strategies. Equipped with basic graphic representation, this software is also helpful for the study of 3D urban form and urban design, which can be further improved by adding some shape grammar functions.

The parametric relational urban model is a robust platform for processing and cross breeding different urban attribute data to generate meaningful reading of the internal relationship of urban fabric. It operates with urban attribute data as both its input and output that are inter-exchangeable. This ensures a universal application of this model on different research/design scenarios, such as planning on population, transportation, land price, public facilities, etc. Besides, it is also possible to supply this model with data gathered from social/cultural perspectives to achieve a holistic view of the urban fabric. As an abstract

conceptual model, the parametric relational model can also be applied on different levels of scale, say from urban design scale to regional management scale.

The future research on the parametric relational urban model/urban plot ratio allocation software can be concluded with two threads. The first one is to make effective connections with available urban database and urban analysis software, so as to supply the similarity matrix construction with sufficient, accurate and even dynamic urban data. For that, direct connections to some GIS and Space-syntax software are of great interest.

The second research thread is to adapt the general similarity matrix to particular research perspective. The general similarity matrix summarizes an overall similarity pattern from multi-layered urban attributes data. However, considering different research perspective, not all layers of urban data will weight equally for the particular research question at study. In the case study of Urban Plot Ratio Allocation software, this question is partially answered by letting designer to setup their customized factor weight combination in a top-down manner, so as to reflect their particular design considerations. However, it is also possible to introduce a genetic algorithm based function to help with searching the optimized factor weight combination. For that, the particular research perspective/question can be regarded as another layer of urban attribute with incomplete information, such as the concept of pendent and existing plots in the case study software. Thus, the research question can be reformulated as, given an urban attribute layer with incomplete information, how to apply the general similarity matrix to define the missing information. In this case, the confirmed information from this incomplete urban attribute layer will be regarded as the predefined condition and used as the reference for reconfiguring the general similarity matrix. It is at this step, genetic algorithm can be introduced to search for the optimized factor weight combination of different urban attributes that built up the general similarity matrix model. The outcome of this genetic algorithm searching process will be a new factor weight combination that unifies the general similarity matrix with the particular relational matrix exhibited by the confirmed information of that incomplete urban attribute layer. In another word, by applying genetic algorithm based optimization, the general similarity matrix can be customized for a particular research question. What need to be noticed here is that, there will be multiple factor weight combinations that can fulfill the tolerance requirement of unifying the general matrix and particular relational matrix. This literally reveals the fact that the very urban condition can be interpreted from multiple angles, and it is up to the designer to choose one particular angle. As for the future parametric relational urban model equipped with genetic algorithm searching function, this can be realized by picking up the favorite combination from a list of suggestions, or by predefining certain attribute factor weight then let the genetic algorithm searching function to supply the rest.

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